LOW PROFILE PIEZOCERAMIC ACTUATORS FOR SMART STRUCTURES

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Abstract

The concept of smart structures is based on intelligent constitutive materials giving the means to react on external stimulation by changing local mechanical properties. The market needs a high degree of integration of all components: sensors, actuators and electronic. Progress has been attained due to ongoing R&D activities. Recently the German Aerospace Center, DLR, Braunschweig has developed a flexible and reliable PZT wafer based design. Progress is also seen in the commercialization of fiber composites. For example, Smart Material Corp. is manufacturing the Macro Fiber Composites, licensed by NASA in a full-scale production. Fraunhofer – IKTS has found a new approach for custom shape fiber composites. The paper is giving an update on availability and developments of low profile piezoelectric sensors and actuators.

INTRODUCTION

There is an increasing need for vibration and shape control in advanced load carrying structures. Leight weight design, increased precision, higher safety, reduced noise and last not least more comfort are the most sought after goals. Conventional technical solutions are based on the use of higher amount of mass, which is in conflict with the demands of the market. An alternative approach is given by the concept of smart structures, which is based on intelligent constitutive materials giving the means to react on external stimulation by changing local mechanical properties of the structure. The approach is based on the integration of sensors and actuators, which are connected to an electronic circuit. This can be a simple passive network, but also a complex micro-controller driven circuit. The market needs a high degree of integration of all components. Beside of integrated sensors and actuators electronic circuits are also expected to become an integrated part of the structure.

Suitable composite material systems that combine load carrying, sensory and active properties are a vital prerequisite for the development of adaptive structures. Due to the overall performance, piezoceramics are considered the most promising basis for active material. The use of thin monolithic piezoceramic wafers and fibers as actuating and sensing material for structural control has been discussed in many publications (e.g.[1]-[5]). However the production of these devices is still very demanding since the extreme brittleness of the piezoceramic material requires sophisticated manufacturing techniques to avoid damages. An appropriate solution for this problem is to pre-encapsulate the brittle piezoceramic wafers or fibers before processing. With this step the piezoceramic is provided with a mechanical stabilization, electrical insulation and electrical contacts. Even though an additional manufacturing step is necessary the advantages predominate. Also the reduction of strain transfer due to the relative soft surrounding material can be considered as low.

Smart structure technology or adaptronics is attaining a rapidly growing market share. Originally developed for the aircraft and space industry, adaptronics is going to be used for advanced product in sports and further industrial branches, like automotive and machine building industry. This has been an important goal of the German industrial project “Adaptronik”. Partners from the automotive-, space-, medical-, engineering- and optical industry participated in the project to enable new adaptive solutions for a wide range of applications. This increased the demand for new, low profile actuators which were already strong due various earlier developments in the US. The present paper gives an update on low profile piezoelectric sensors and actuators.

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COMMERCIAL LOW PROFILE ACTUATORS AND PILOT PRODUCTS

At present, only three different low profile actuator types are commercially available. These designs are arising from the R&D work at MIT in the years 1991 / 92 funded by the US Department of Defense. A short overview classified as wafer based and fiber based design is given below.

PZT Wafer Based Design

The US based company ACX has developed encapsulated patches called Quickpack® . The encapsulation is achieved by a wafer coating (polyimid) with copper leads to contact the metallized PZT wafer. Main supplier is now the US based company MIDE Technology Corp., Medford, which has licensed the Quickpack® technology recently. 14 different actuators are offered, the ceramic wafer thickness is ranging between 125 µm ... 250 µm. The patch size covers 40 mm x 25 mm to 110 mm x 40 mm. Stacks are available to raise the generative force. NASA has done a similar approach with the development of the so-called “flex-patch” .

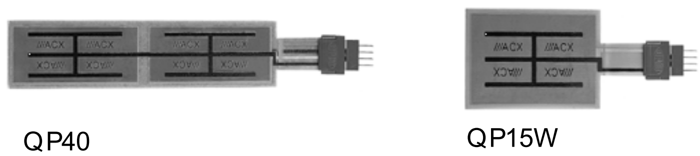


Fig. 1: PZT – Wafer derived low profile actuators, developed by ACX, now supplied by MIDE.

The development of a new technology for the manufacturing of adaptive structures on the basis of piezoceramic materials was an important goal of the German industrial project “Adaptronik”. German Aerospace Center DLR Braunschweig has developed a new modular concept for pre-encapsulated actuators [6]. During this manufacturing step the piezoceramic material is provided with a mechanical stabilization, an electrical insulation, electrodes and reliable electric contacts. The multifunctional elements are characterized by an increased fault tolerance, good long term properties and an easy handling. Due to the modular concept, the multifunctional elements can be designed to meet a great variety of different requirements. This involves for example driving voltages, size and shape of the elements and the piezoceramic material itself. See Fig. 2.

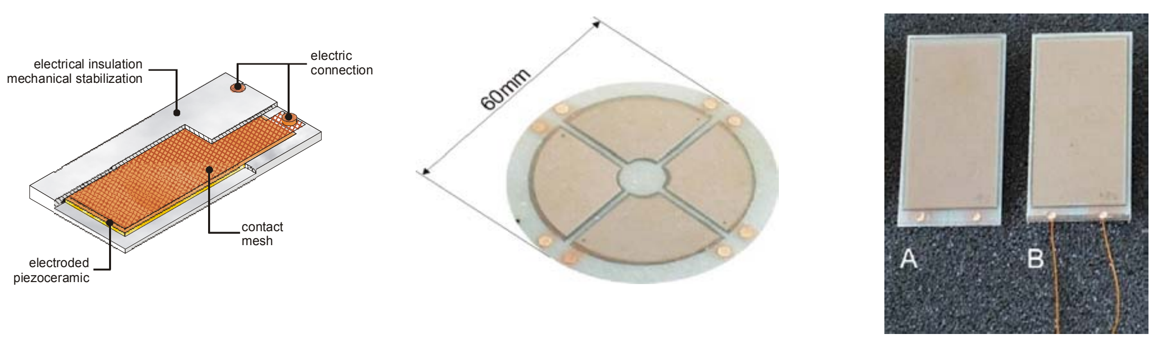


Fig. 2 : Design and examples of PZT wafer deduced low profile actuator, as developed by German Aerospace Center (DLR), Braunschweig.

PZT Fiber based design

The so-called AFCs (active fiber composites, production by Continuum Photonics Inc., former Continuum Control Corp) are using cylinder shaped PZT fibers, prepared by extrusion or textile spinning technology (VSSP, ALCERU®). Interdigital electrodes are used for electric field coupling.

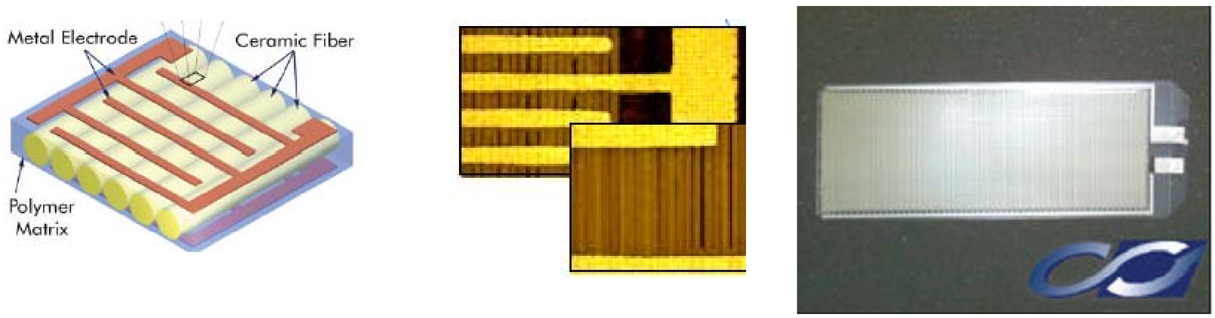


Fig. 3 : AFC design and device, developed by CCC.

The so-called MFCs (macro fiber composites) consist of rectangular piezo-fibers sandwiched between layers of adhesive and polyimide film with electrodes. This film contains interdigitated electrodes that transfer the applied voltage directly to and from the piezo fibers. This assembly enables in-plane poling, actuation, and sensing in a sealed, durable, ready-to-use package. MFCs have been developed by NASA and are now produced by Smart Material Corp.

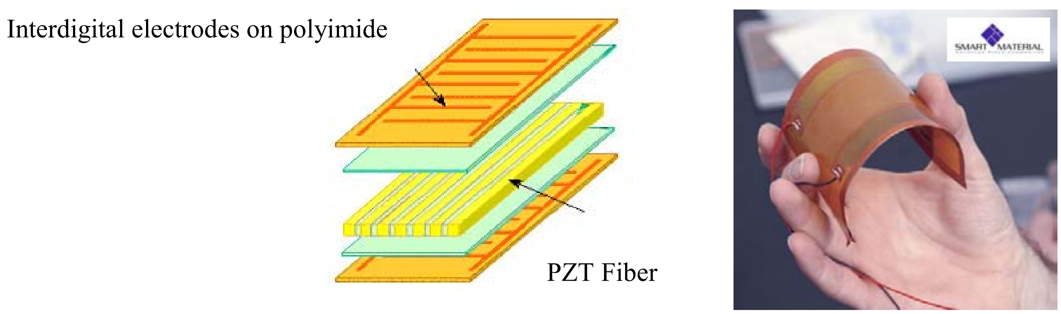


Fig. 4 : MFC, design and device, as developed by NASA and produced by Smart Material

Fraunhofer – IKTS has developed a different type of fiber composite based on machining of PZT fiber – epoxy blocks, called SFC (Shape Fiber Composite). In a first step PZT fibers are arranged randomly or in a nearly ordered manner. Second, the arranged fiber bundles are infiltrated with an epoxy resin. After curing the PZT/epoxy composite, the material undergoes conventional machining, like dicing, turning, grinding, or drilling to obtain different shapes to fit the desired application. Due to the possibility to shape the material with standard machining procedures the number of design variation can be increased considerably. With its 1-3 connectivity, the SFC properties are also anisotrop. The technology has been licensed to Smart Material Corp.

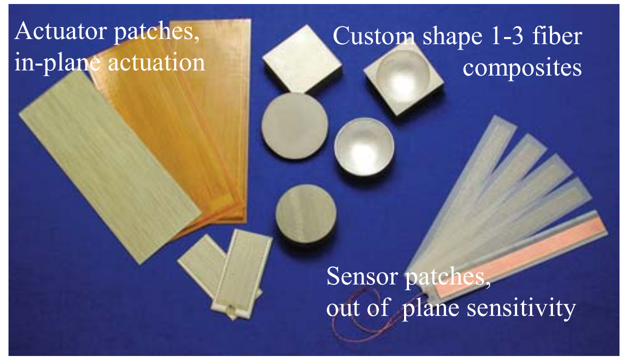


Fig. 5 : Piezofiber composites as block material (left) and semi-finished products, developed by Fraunhofer - IKTS

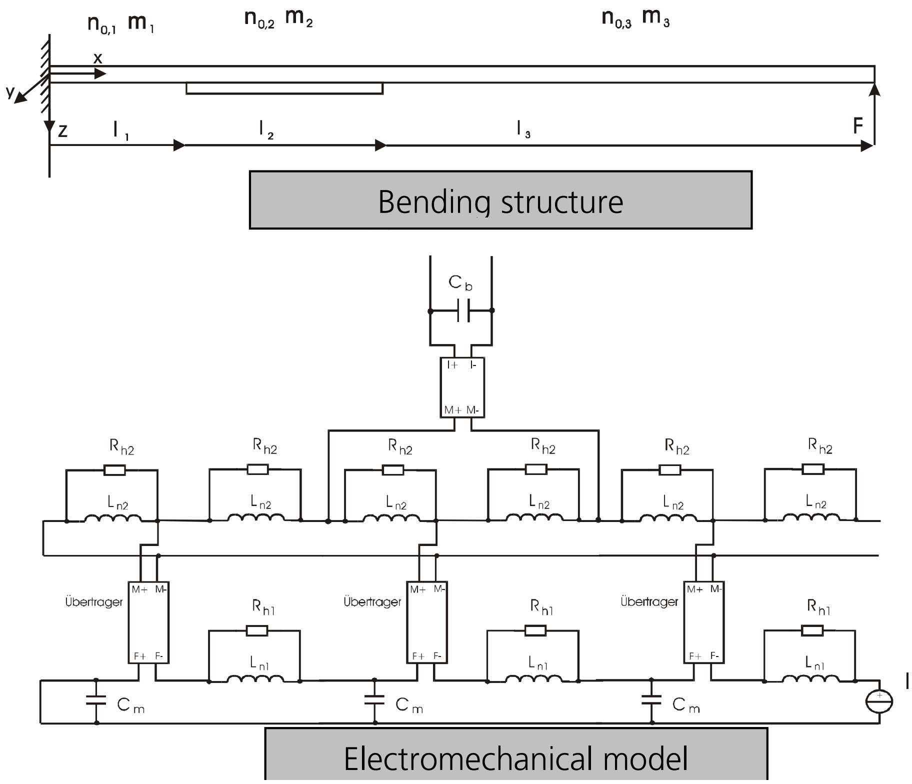
R&D ON LOW PROFILE ACTUATORS

The goal of the current R&D efforts is to develop new elements with improved performance that can easily be adapted to different applications. With respect to the great variety of industrial demands, standardized solutions still do not exist. Ongoing R&D is addressing different levels of product improvements:

- constitutive phases (piezoceramic, epoxy, insulating and conductive materials)
- scale, shape and connectivity defining the piezocomposite
- device design, especially mesoscopic electrical and mechanical field distribution, interfaces and geometry
- coupling to the load carrying structure (size scaling, placement) and the electronic circuitry (voltage, current, time processing) .

Knowledge on all these levels is necessary to improve device performance and the efficiency for structural control. Progress has recently been attained in the availability of piezoceramic elements (rectangular and circular fibers, tubes, different materials), the device design (geometry and materials for max authority, efficiency, lowest drive voltage). The correlation between structure and the design and placement of the actuators has also been analyzed showing a strong interaction. In other words, patches and structure must be designed in close combination.

A basic approach has been found for optimum design of the mechanical, piezoelectric and electrical parts of active structures. In Fig. 6 a bending structure with applied piezoelectric actuator is shown, as well as the deduced electromechanical model. The bending structure is completely described by the equivalent network that can be optimized using commercial software tools (PSPICE, etc.)



CONCLUSION

Adaptronics is currently used in first applications. Because basic performance parameters are considerably improved, like for example energy economy, precision and comfort, a widespread use is expected in the next future.

The availability of low profile actuators and sensors has improved considerably during 2002/ 2003. The availability of commercial products will match the demand of the industry in 2004. Thus, major prize reduction is expected during the next 12 months. With a maturing market we also expect to see a shift of the applications from the current defense and sport items sector to industrial applications and general consumer goods.

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